

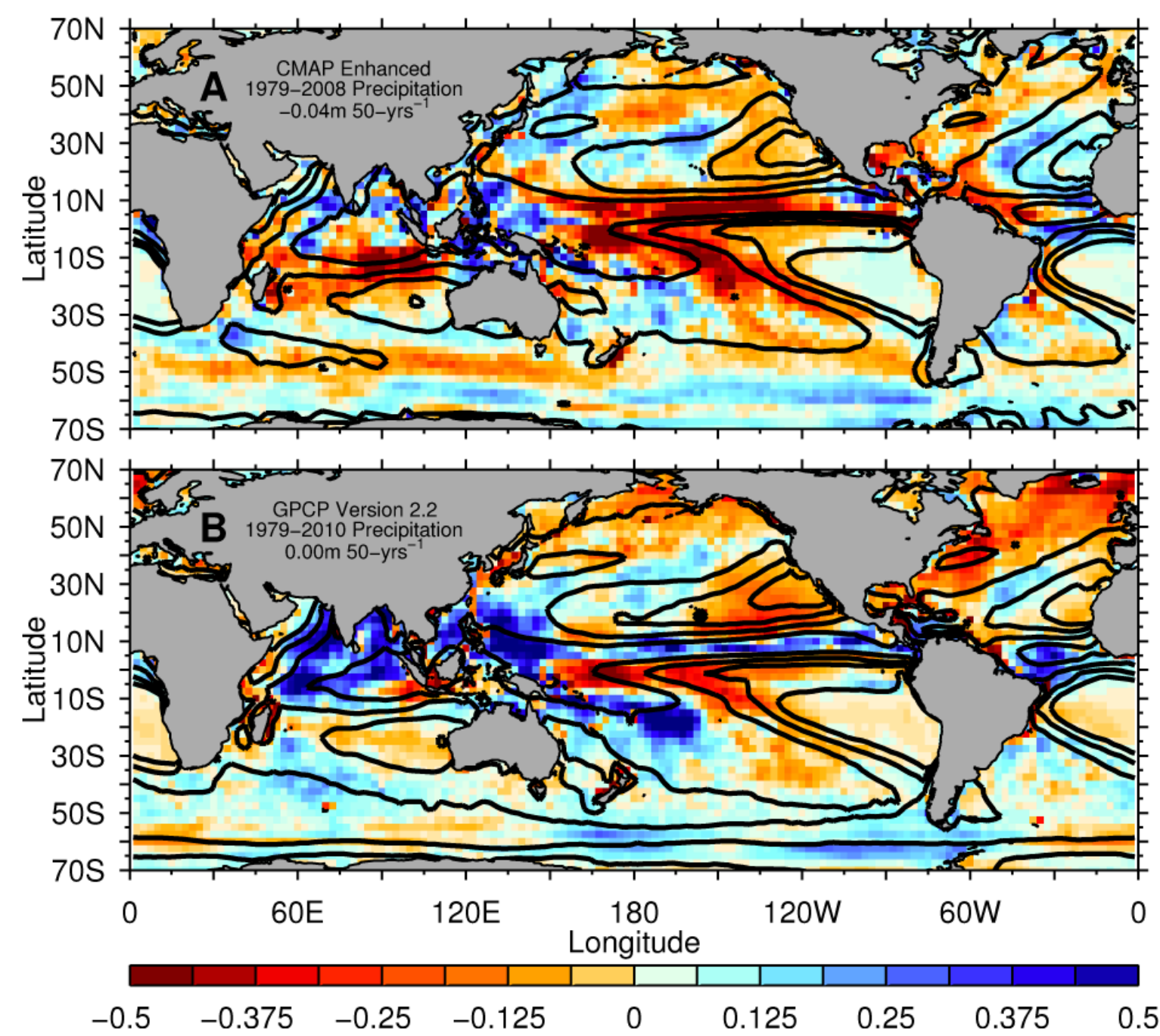
Global ocean salinity: CMIP3 & CMIP5 versus observed change estimates of a strengthened water cycle

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Little consistency exists between estimates of satellite-observed rainfall changes

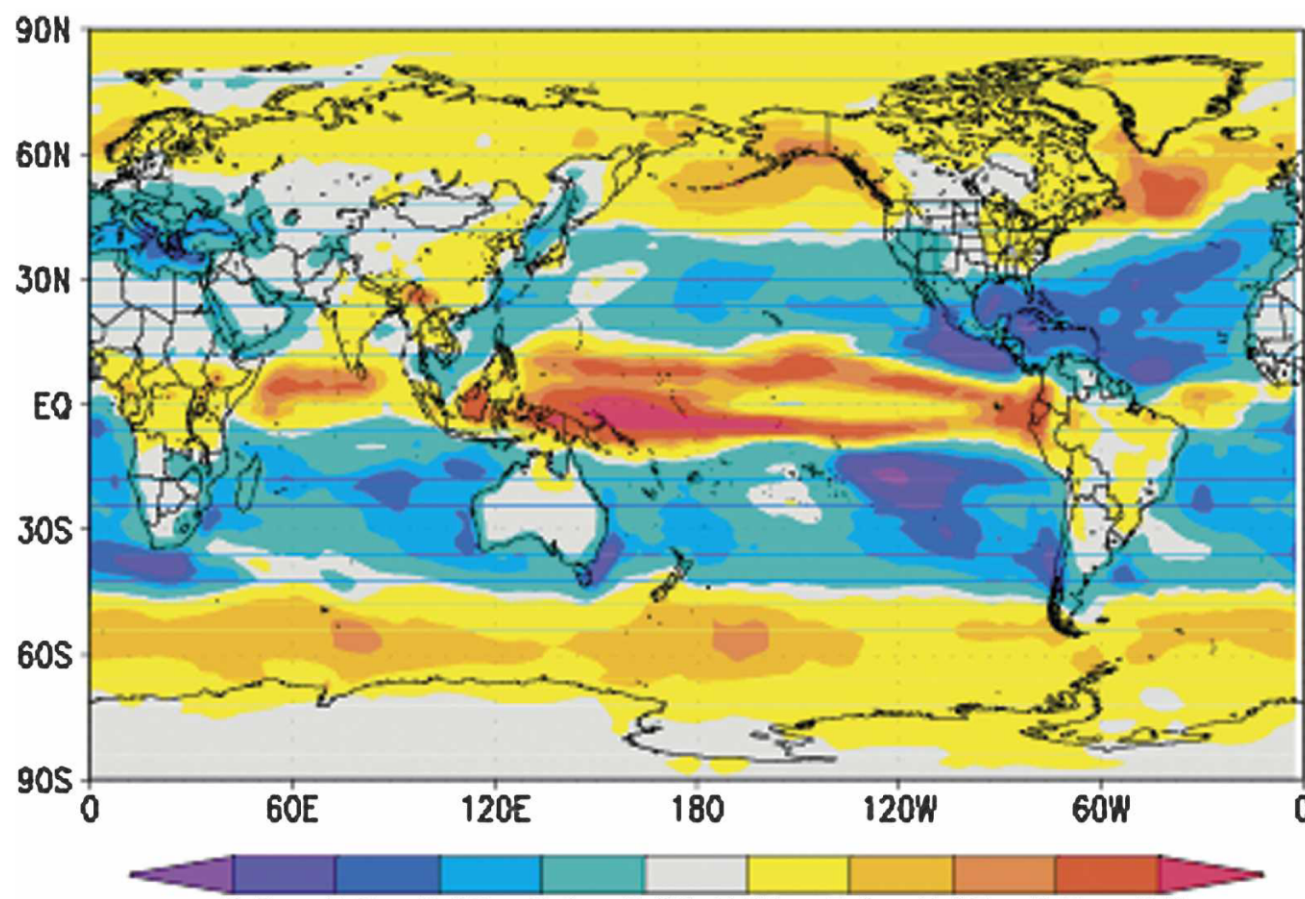
1979 to near-present resolved trends in surface precipitation: A) CMAP B) GPCP V2.2



- Two available global precipitation products and their long-term trends obtained from annual-mean climatological values (units are absolute changes scaled to represent m 50-year⁻¹)
- Data products have largely the same input data
- Patterns of trends indicate an almost inverse spatial pattern
- As a consequence an unambiguous understanding of how the Earth's water cycle has intensified is not presently available from existing rainfall observations

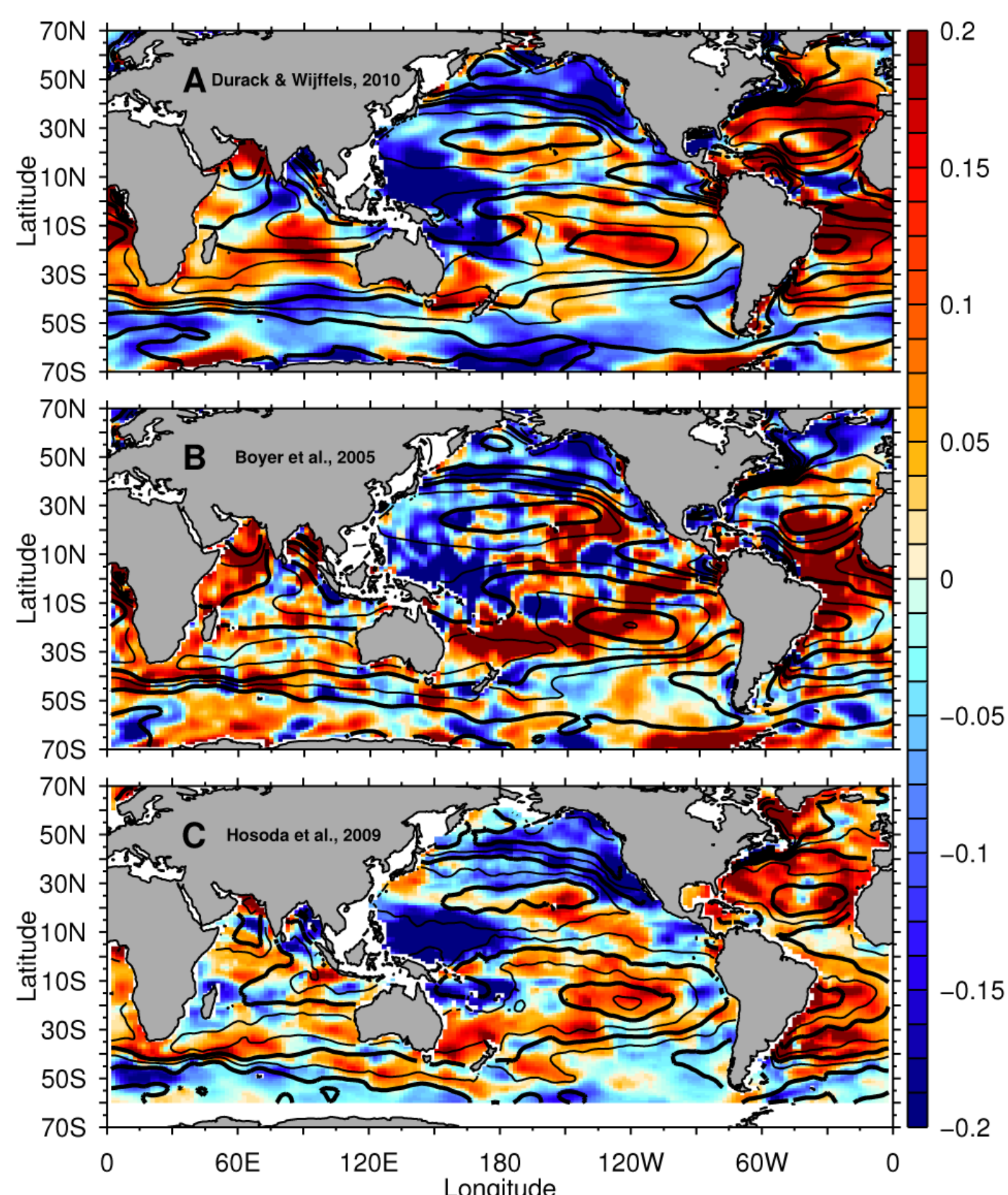
Water cycle Change: Expectations for a warming Earth

- Warming of the global surface and lower atmosphere is expected to strengthen the global water cycle
- This change is largely driven by the ability of warmer air to hold and transport more moisture
- The intensification is expressed as enhanced patterns of surface freshwater fluxes, evaporation (E) and precipitation (P) as expressed in the figure below obtained from an ensemble mean of CMIP3 models (Held & Soden, 2006; P-E, so red regions are projected to increase P and blue regions increased E over the annual cycle)
- As E-P sets the spatial pattern of ocean surface salinity, any changes to E-P over the observed record are likely to be visible in long-term trends of ocean salinity, assuming that circulation and mixing to first order remained unchanged over the observed period



Independent estimates of observed salinity changes show a more coherent picture

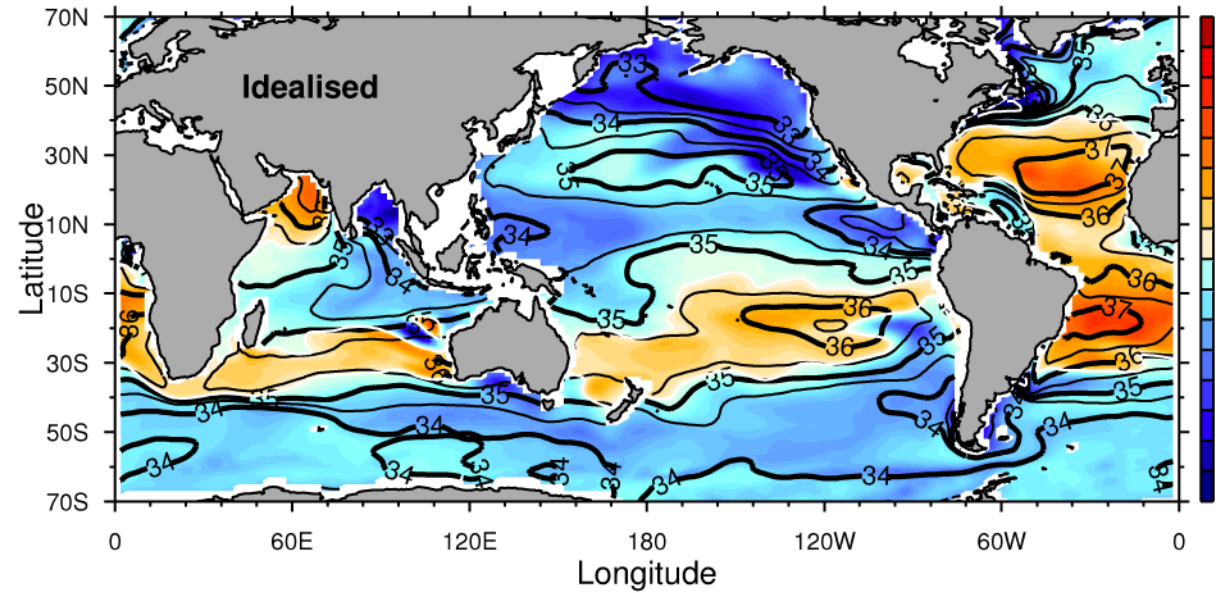
50-year trends in near-surface ocean salinity from 3 independent observational studies:
A) Durack & Wijffels, 2010 B) Boyer *et al.*, 2005
C) Hosoda *et al.*, 2009



- Broad-scale patterns of salinity change are apparent in each of the independent analyses (units are absolute changes scaled to represent PSS-78 50-year⁻¹)
- Fresh regions (western Pacific Warm Pool) are becoming fresher
- Salty regions (Southern Hemisphere sub tropics) are becoming saltier
- Salinity pattern amplification is also apparent in subsurface data
- Patterns broadly agree with the expected response of a wet-gets-wetter, dry-gets-drier atmospheric response
- Surface as well as subsurface patterns for each independent ocean basin suggest coherent changes are already underway

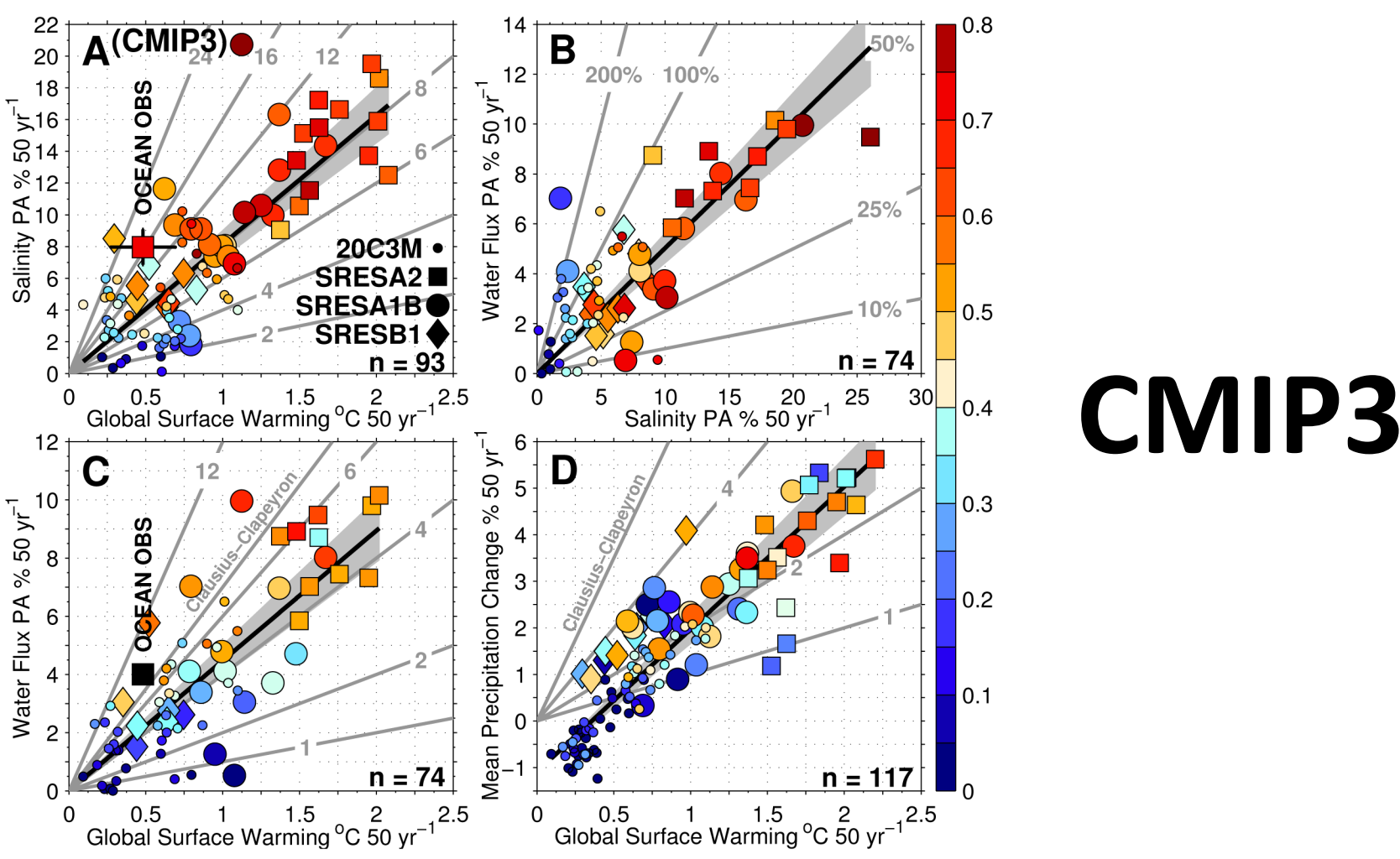
Making the link: E-P driven salinity change assessed in idealized ocean-only simulations

- Ocean-only simulations were used to independently test whether idealized simulation of water cycle enhancement (E-P) is captured by salinity
- Simulations tested 4 magnitudes of change, with 5, 10, 15 and 20% imposed E-P trends over 50-years
- In the broad-scale, resultant ocean salinity changes agree well with those found in observed analyses
- Patterns of change at the surface (below), subsurface and for each basin (not shown) suggest that long-term salinity trends are an effective marker of water cycle change



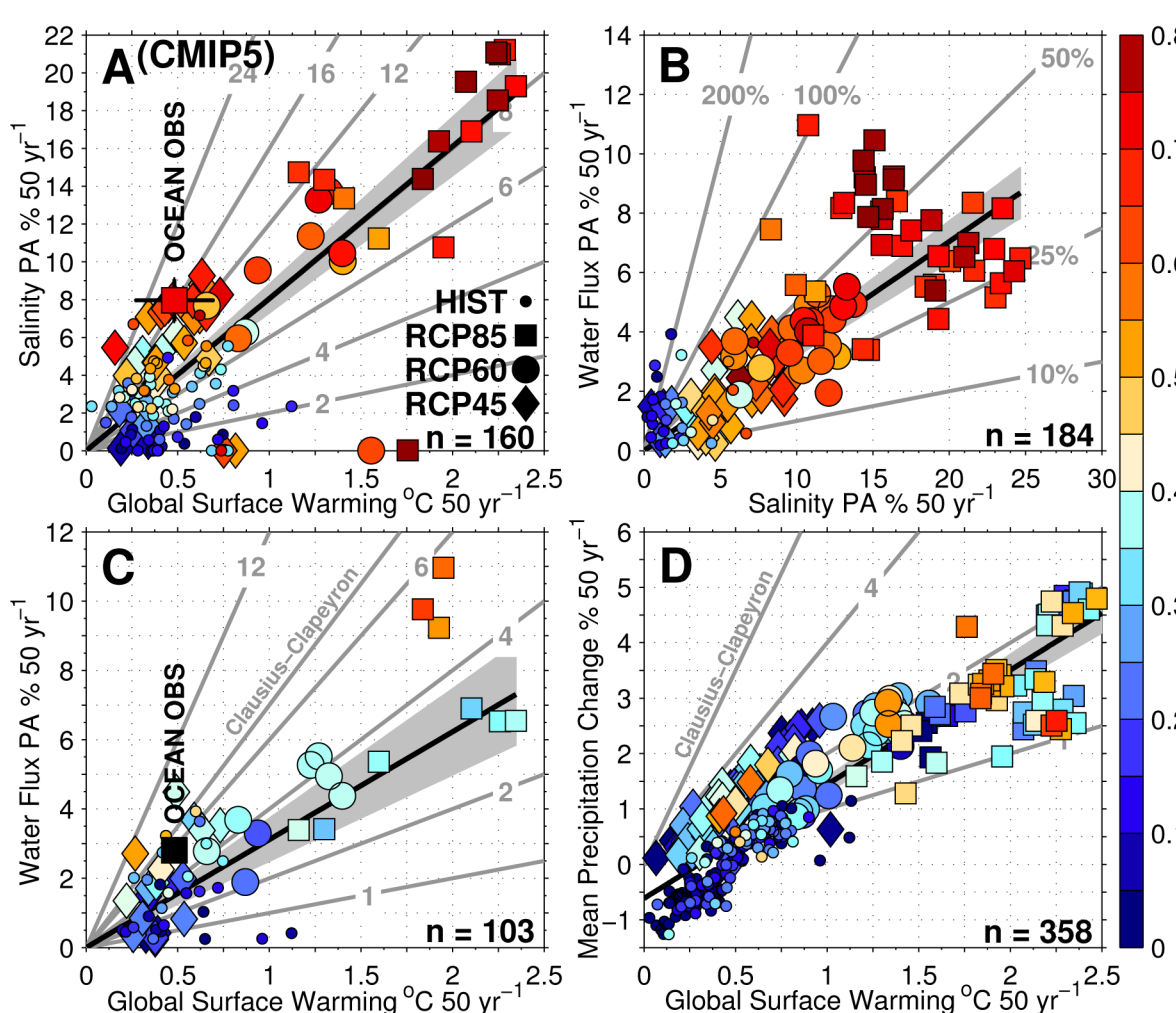
CMIP models provide an insight into how the coupled ocean-atmosphere water cycle responds to a warming climate

50-year trends in modeled near-surface salinity, E-P, their inter-relationship and mean rainfall changes from CMIP3 & CMIP5 model simulations



- CMIP models suggest that salinity is a valid marker of water cycle change, with a strong relationship between E-P and surface salinity change in both the CMIP3 and CMIP5 model suite
- Increased salinity pattern amplification (PA) follows a fairly linear trajectory (panel A) and is highly temperature dependent
- Increased E-P PA is also temperature sensitive (panel C), though shows more scatter than salinity change estimates
- Using CMIP models to scale observed salinity change to derive an inferred E-P change yields 3-4% for the 1950-2000 period

CMIP5

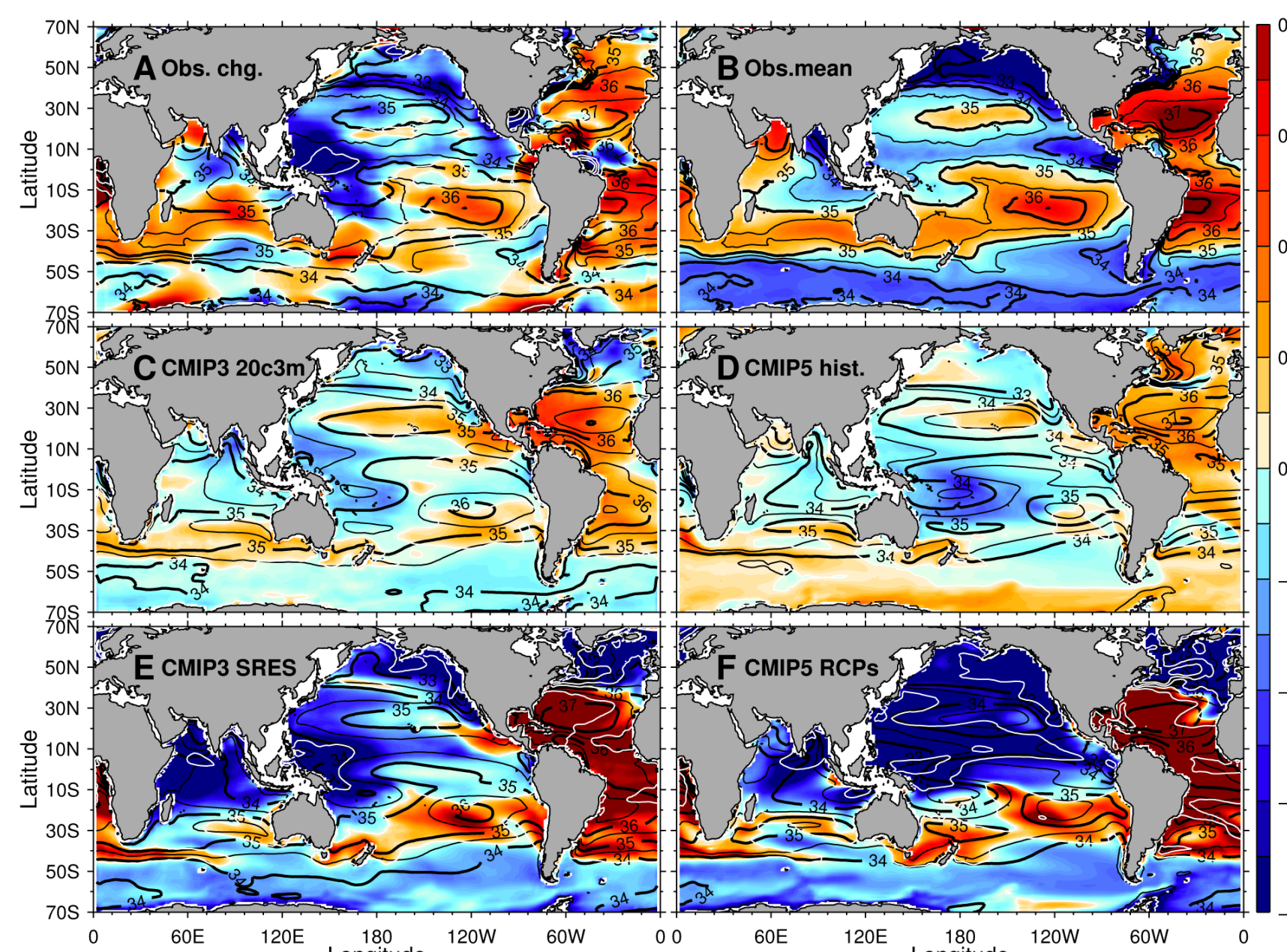


Methods

- Firstly an analysis of the long-term trends in ocean salinity was undertaken. This involved a dual analysis to determine ocean property changes in both pressure and isopycnal coordinates and was documented in an earlier paper Durack & Wijffels (2010)
- The focus of the present study is to assess changes to the global water cycle through the analysis of salinity observations (above) and ocean fields from the CMIP3 and CMIP5 model suites using a model observation synthesis approach
- Investigate the relationship between changing ocean evaporation-precipitation (E-P) salinity in available models
- Validate that an idealized ocean model run with enhanced E-P returns salinity change patterns similar to those observed – suggesting that salinity is a valid marker of water cycle (E-P) changes on climate scale (>30 years)
- Assess whether the Pattern Amplification (PA) expressed in observed change estimates is apparent in the CMIP model suite
- Infer observed E-P changes from salinity changes calibrated by the CMIP E-P/salinity change relationship

CMIP models underestimate trends when compared to historical observations

50-year trends in near-surface salinity
A) Observed change B) Observed mean salinity
C) CMIP3 1950-2000 D) CMIP5 1950-2000
E) CMIP3 2050-2100 F) CMIP5 2050-2100



- The new analysis provides strong evidence that the global water cycle has intensified over the observed record
- Results suggest that climate changes captured by more than just global temperature change is underway
- Preliminary results from the latest available data suggest an improvement in resolved salinity changes is apparent when comparing CMIP3 to CMIP5
- CMIP models seem to systematically underestimate the rate of change as captured in observed salinity estimates for the last 50-years, yielding half the sensitivity (8% °C⁻¹) compared to observed estimates (16% °C⁻¹)
- The implications of such an apparent underestimation of the rate of change for model projections of 21st century and beyond are unknown and require further investigation
- Ongoing re-evaluation of the observed estimates of change are also planned

References

- Boyer, T. P., S. Levitus, J. I. Antonov, R. A. Locarnini and H. E. Garcia (2005) Linear trends in salinity for the World Ocean, 1955-1998. *Geophysical Research Letters*, **32**, L01604. doi: [10.1029/2004GL021791](https://doi.org/10.1029/2004GL021791)
- Durack, P. J. and S.E. Wijffels (2010) Fifty-Year Trends in Global Ocean Salinities and Their Relationship to Broad-Scale Warming. *Journal of Climate*, **23**, pp 4323-4362. doi: [10.1175/2010JCLI3377.1](https://doi.org/10.1175/2010JCLI3377.1)
- Durack, P. J., S. E. Wijffels and R. J. Matear (2012) Ocean Salinities Reveal Strong Global Water Cycle Intensification During 1950-2000. *Science*, **336** (6080), pp 455-458. doi: [10.1126/science.1212222](https://doi.org/10.1126/science.1212222)
- Held, I. M. and B. J. Soden (2006) Robust Responses of the Hydrological Cycle to Global Warming. *Journal of Climate*, **19**, pp 5686-5699. doi: [10.1175/JCLI3990.1](https://doi.org/10.1175/JCLI3990.1)
- Hosoda, S., T. Suga, N. Shikama and K. Mizuno (2009) Global Surface Layer Salinity Change Detected by Argo and Its Implication for Hydrological Cycle Intensification. *Oceanography*, **65**, pp 579-596. doi: [10.1007/s10872-009-0049-1](https://doi.org/10.1007/s10872-009-0049-1)

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